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REPORT OF INVESTIGATIONS/1991

Self-Contained Self-Rescuer Donning Proficiency at Eight Eastern Underground Coal Mines

By Charles Vaught, William J. Wiehagen, and Michael J. Brnich, Jr.

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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UNIT OF MEASURE ABBREVIATION USED IN THIS REPORT

pct	percent

SELF-CONTAINED SELF-RESCUER DONNING PROFICIENCY AT EIGHT EASTERN UNDERGROUND COAL MINES

By Charles Vaught,[1] William J. Wiehagen,[2] and Michael J. Brnich, Jr.[3]

ABSTRACT

The U.S. Bureau of Mines evaluated the self-contained self-rescuer (SCSR) donning proficiency of 243 miners. These workers were from eight underground coal mines in the eastern United States. The objectives of the study were (1) to gather information on skill levels, since all miners in the study had prior instruction and opportunity to practice donning the apparatus, and (2) to summarize a quality control procedure useful in conducting periodic evaluations of donning proficiency. The sampling procedure used proved to be both reasonable and efficient in gathering information on training effectiveness. It also provided a good statistical base for making informed site-specific decisions regarding SCSR training needs. Results from the observed samples at each of the eight mines indicate a wide variability across sites. The rate at which miners failed to isolate their lungs varied from 3.3 to 40.0 pct. Concomitantly, proficiency rates (miners either performing adequately or demonstrating a perfect 3+3 sequence) ranged from 13.3 to 63.3 pct.

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INTRODUCTION

SCSR training dates to mandatory deployment (*1*)[4] of the apparatus in underground coal mines in 1981. Questions about the nature and quality of this training, and about the ability of workers to use the device, were translated into specific regulatory action in 1987 and 1988 (*2-3*). The resulting regulation required mine operators to include a hands-on component in their SCSR training. Information on miners' donning skills is not typically gathered, however. Additionally, miners are not usually refreshed or evaluated between training cycles. Hence, the content of annual SCSR instruction is fairly static, with federal and state requirements providing the impetus for most retraining.

One should not assume that once-a-year practice in a classroom leads to SCSR donning proficiency. Such an assumption relegates the training to simple compliance with regulations, and does not necessarily result in adequate donning skills. Better ties between training and performance, however, are only possible through the collection of proficiency data. In short, attempts to improve the training process are likely to be ineffective unless they are linked to an empirical base.

This study was designed as an empirical assessment of SCSR donning proficiency and for providing a set of sampling guidelines useful in determining, at the mine-wide level, the skills of underground workers. From January through March 1989, the U.S. Bureau of Mines participated in an evaluation of SCSR donning at eight sites in the eastern United States. The evaluation was with a canvass being conducted by the Mine Safety and Health Administration (MSHA), although the Bureau's activity was considered to be an independent research project. A brief report of the procedures used and a discussion of the findings follows.

PROCEDURE

This section details the procedure used to select the mines and miners comprising the study sample. It also discusses the methods used to collect performance data and to differentiate donning proficiencies.

SAMPLING MINES AND MINERS

Researchers obtained a listing of candidate mines in a limited geographic area. They next determined the type of SCSR in use at each of these operations. The mines were then grouped by apparatus (MSA, CSE, Ocenco, and Draeger),[5] and two mines were randomly selected from each category. The MSHA education and training specialist responsible for evaluating each particular mine was then contacted, and arrangements were made for a mutually convenient time to conduct the on-site assessment.

At the mine, an underground section was selected randomly for evaluation. If the mine produced on more than one shift, the researchers stayed on that section and evaluated all workers (until a total of at least 30 had been obtained). If the mine produced only on one shift, or if there was no possibility of sampling 30 workers on the initial section selected, a second section was drawn randomly for inclusion in the sample.

The data collection protocol required two researchers to evaluate each donning trial. Once the evaluation team arrived on an underground section, miners were brought back from the face one at a time. One of the Bureau investigators explained that this study was concerned with how well miners could put on the SCSR in the event of an emergency. The subjects were informed that their cooperation in the study was strictly voluntary. After receiving the worker's consent to participate, (nobody refused), a short interview was conducted to obtain basic demographic data such as age, experience, and job title. It was explained to the individuals that they should don the SCSR just as they would if it were necessary to escape the mine, and to do the entire procedure.[6] One of the evaluators next requested the miner's permission to videotape the donning trial, explaining that the videotape would be used to verify the donning evaluations. Finally, the workers were asked to place themselves behind an SCSR training simulator, which was resting on the mine floor and to prepare to don the device.

EVALUATING DONNING PERFORMANCE

At a signal from the evaluator operating the video camera, the miners donned the SCSR (without prompting) and signaled that they had finished by raising their hand. While one researcher videotaped the entire procedure, the

[4]Italic numbers in parentheses refer to items in the list of references at the end of this report.

[5]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

[6]The miner was told that a cleaned and disinfected mouthpiece assembly had just been installed on the training model and was shown the remaining supply of disinfected mouthpiece assemblies, each packaged in its own clear plastic bag.

other evaluated and timed the trial. If an individual declined to be videotaped, both evaluators noted and timed the performance so that results could be cross-checked.

A total of 243 miners were evaluated. One mine, mine G, refused to allow videotaping. In addition, 27 individuals at other operations declined to be videotaped. In all, however, researchers were able to collect 185 videotaped performances to compare with initial evaluations. In some cases (less than 10 pct), an analysis of the videotapes led to alterations of the original assessment. In the case of those for whom there were no videotapes, the two evaluators looked over their forms and, where there were discrepancies, reached an agreement on the resolution. The only other potential problem in finalizing the data occurred with those miners who refused to insert the mouthpiece. As it turned out, there were only four miners in this category. The data from their trials was treated as missing information. In summary, the preliminary analysis that follows is based on data that have been closely scrutinized, and is an accurate representation of the proficiency levels found in the sample at the eight mines.

ASSESSING PROFICIENCY LEVELS

Donning performance and proficiency were assessed using the evaluation form (fig. 1) distributed by the National Mine Health and Safety Academy as part of the 3+3 SCSR instructional package (*4*). Use of this form has two primary functions: (1) as an instrument to measure an individual's donning performance, and (2) as a feedback device to the individual performing the task. Accurate knowledge of results is necessary on both an individual and group level. Without feedback to the trainee, there is not likely to be any skill improvement. For those who allocate training resources, detailed information about patterns of group actions offers a valuable baseline of performance to target for improvement.

The 3+3 evaluation system allows researchers to make reasonably fine distinctions among donning proficiency levels. To assist in examination of the performance data, a five-fold typification was used, dependent upon the degree of proficiency demonstrated. In the final analysis, whether one passes or fails in the real world would be determined by the ability to use one's SCSR well enough to survive an attempt to evacuate through an unbreathable atmosphere. There is little doubt, however, that someone who can put on and use the apparatus with some degree of competence will have a better chance than someone who cannot.

Descriptive comments taken from actual evaluation forms are profiled below:

Failing: Failure to isolate lungs

- The mouthpiece flange was outside the miner's lips and miner did not adjust straps.
- The miner put the SCSR on backwards. The mouthpiece and noseclips pulled out - miner put the mouthpiece back in, but forgot the noseclips. The miner did not adjust the waist or neck straps.
- The miner failed to activate the oxygen and forgot to put on the noseclips.

Poor: Lungs isolated but not escape ready

- The miner stood up to put the SCSR on. The mouthpiece and noseclips pulled out because the trainee failed to adjust the neckstrap. The miner appeared to be very confused during the entire donning sequence.
- The miner did not loop the neckstrap. Instead, miner put the waist strap around the neck. The miner also put the goggles on over the glasses and forgot to put the hardhat back on.
- The miner failed to adjust the neckstrap; as a result, there was noticeable tension on the breathing hose.

Marginal: Confusions that could cause escape problems

- The miner twisted the neckstrap around the breathing hose.
- The miner did not put on the goggles and failed to fasten the waist strap. The noseclips slipped off, but the miner put them back on.
- The miner adjusted the neckstrap after looping, but never secured the waist strap. The miner took the mouthpiece out to look for noseclips, and put it back in once they were found. The miner initially hung the goggles around the neck. The miner had to remove the mouthpiece and noseclips to put the goggles on. After donning the goggles, the miner replaced the mouthpiece and noseclips.

Adequate: Escape worthy

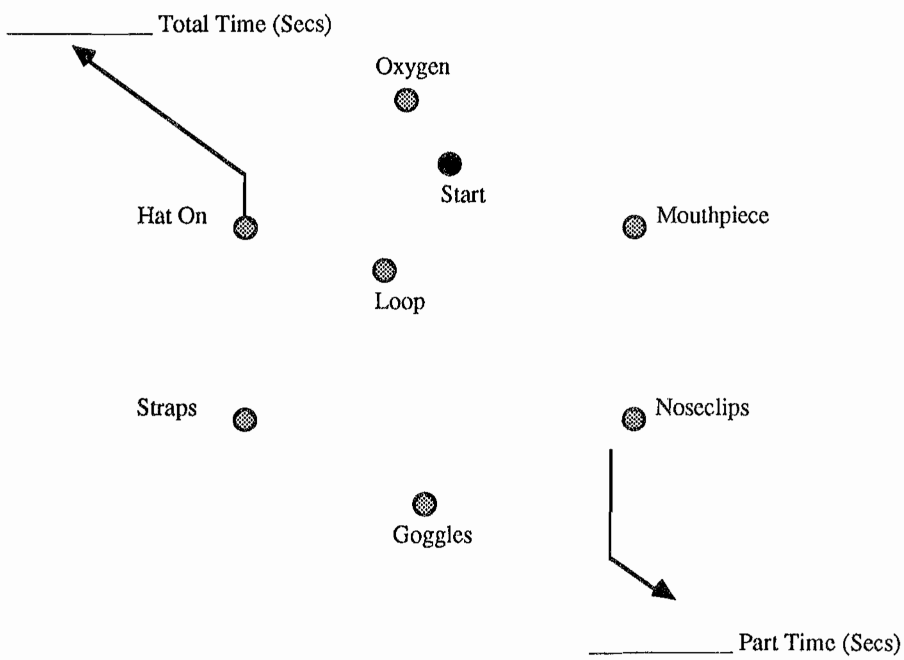
- The miner adjusted the neckstrap before activating the oxygen.
- The miner adjusted the neckstrap before donning the goggles. After the miner put the hat on, the miner fastened and snugged the waist strap.
- The miner looped the neckstrap over the hat and lamp cord.

Evaluation for ______________________________ Date ________________

Serial Number ___________ Mine ____________________ Trial # ______

Tape (Y or N) _____ Type of Unit _____________

1. Connect the dots in the diagram below to show the steps the trainee took in donning the SCSR. If a step was started but not finished, dip the line toward the step. Do not touch the dot if the step was not completed or was done incorrectly.



2. After the task is completed, please list any errors that need to be corrected and then review these errors with the trainee.

____

____

____

____

____

____

Figure 1.—Evaluation form for use in teaching and assessing 3+3 donning method (*4*).

Perfect: Escape worthy

- The miner performed a perfect 3+3 sequence.
- The miner did a perfect sequence. The waist strap should have been slightly tighter.

As can be seen, failing merely applies to an individual's omission of one or another of the steps necessary to isolate the lungs. In point of fact, miners in both the failing and poor categories would be considered less than proficient with the apparatus. Individuals in the adequate and perfect categories, on the other hand, would be considered proficient. What the five-fold typification allows, however, is a generalization of the kind of errors that are being committed. As one reads the descriptive comments from failing to perfect, it can be seen that a qualitative change occurs in the actions that are being described. To provide a visual representation of the categories, figures 2 through 6 show evaluation forms upon which several individuals' actual performances have been recreated. The category in which a particular performance falls is marked on the space Trial #. These categories are: F = fail, P = poor, M = marginal, A = adequate, and PT = perfect.

PROFICIENCY LEVELS AT EIGHT MINES

This section presents a graphic profile of proficiency in the samples at the eight mines in the study. These graphical profiles are used to illustrate and differentiate performance patterns within and across the sample.

When looking at the pie charts in figure 7, one should keep three factors in mind. First, recency of training has a large impact on how well people perform. Even well-trained individuals forget things over time. Second, some trainers have used a modified version of the 3+3 donning method in their training. Therefore, that mine would probably have no individuals in the perfect category, because perfect simply refers to a perfect 3+3 sequence. If the miners are well-trained, however, there will be many in the adequate category, and adequate performance is also proficient performance. Third, different mines have different apparatus. However, while the type of apparatus has been found in previous studies to be a controlling variable in predicting donning times, it has not predicted performance (*5*). With these caveats in mind, it can be seen that there was a significant amount of variation in the sample.

Mine A, whose safety coordinator had just trained everyone using the 3+3 method, exhibited the highest degree of proficiency. Mine C, whose miners had also been trained recently (within the past month), also had a significant number of workers who would be considered proficient. An interesting aspect at mine C, however, is the large percentage of people in the marginal category. This would seem to indicate that so-called secondary steps (such as strap adjustment and donning the goggles) either had not been stressed during training, or had been forgotten very quickly. Mine B, which had only 6 pct failing to get their lungs isolated, had a disproportionate number of miners who performed poorly (50 pct). One miner's comment, which might explain this anomaly, was that they were taught to do the critical steps and delay securing the apparatus until they were on their way out of the mine. The two mines with the highest percentage of workers who must be considered less than proficient were mine F (with only 10 pct in the adequate category) and mine H (where 40 pct failed to isolate their lungs).

Perhaps the most significant variable in determining miners' SCSR donning proficiency is how they are trained. There are some general principles of motor task training which, when applied to SCSR instruction, will yield significant results. First, prepractice instruction is very important. This is the point at which the trainee is introduced to the task and shown what is expected of him or her. Research has indicated that attention to detail at this stage is critical if the trainer expects his or her people to become proficient. Second, the individual learning a motor task (such as how to put on a SCSR) must have the opportunity for thorough, consistent, hands-on practice. This practice should be repeated until the person achieves competence. Thoroughness means that the trainee should do all the steps in a task, and do them properly, just as he or she would in an actual situation. Consistency means that the person performs the task the same way every time. Third, feedback is necessary. There is an extensive body of literature showing that when a person performs a motor task, he or she must be allowed to do the task without interruption. Once the task is completed, however, the individual should be given detailed knowledge of his or her performance. If this is not done, little learning takes place. Fourth, for seldom-used motor skills (such as SCSR use), the person must have a periodic refresher in the form of practice.

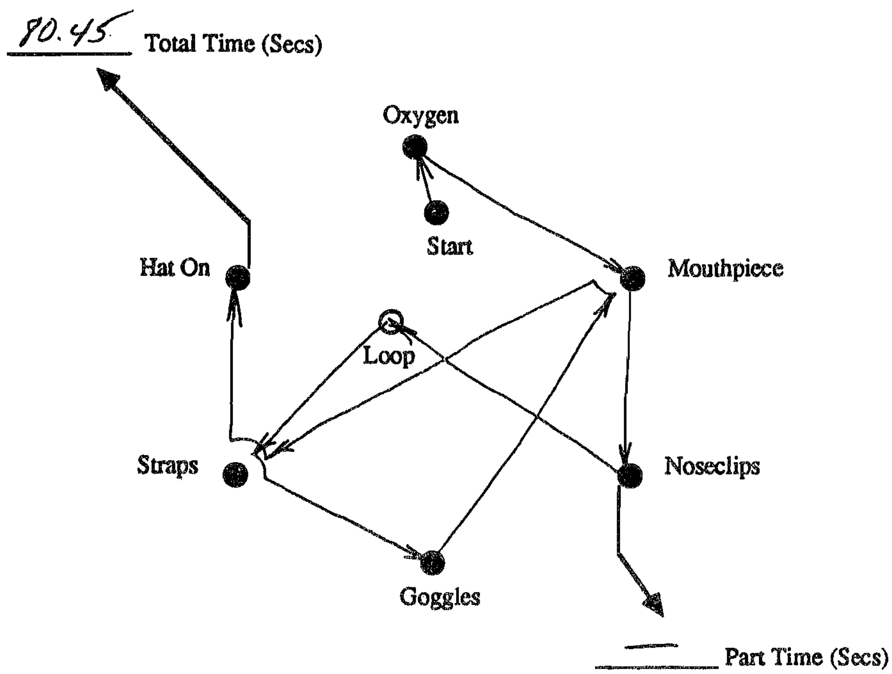
Figure 8 illustrates the points made above. It compares mine A, which had the highest proficiency level in the present sample, with a western mine (mine J) where all workers were given thorough, consistent, hands-on training with periodic follow-up evaluations and opportunities for practice.

The miners at the western site were all trained on-shift during production, but were nevertheless trained according to the motor learning principles discussed above. First, Evaluation for AR Date 1-1-89

Serial Number 805 Mine B Trial # F

Tape (Y or N) Y

1. Connect the dots in the diagram below to show the steps the trainee took in donning the SCSR. If a step was started but not finished, simply dip the line toward the step. Do not touch the dot if the step was not completed or was done incorrectly.



2. After the task is completed please list any errors that need to be corrected and then correct them.

- PUT UNIT ON BACKWARD
- MP AND NC PULLED OUT DUE TO LACK OF STRAP ADJUSTMENT.
  MINER PUT MP BACK IN BUT FORGOT TO PUT NC BACK ON.
  HE HAD POOR MP SEAL SECOND TIME
- NO STRAP ADJUSTMENT

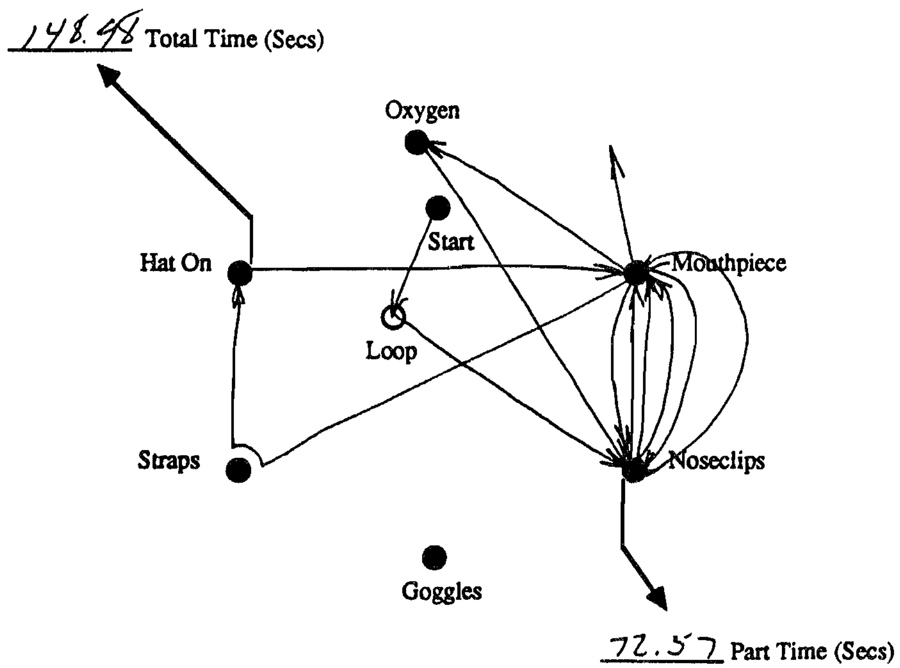
Figure 2.—Evaluation form for failing performance.

Evaluation for HK Date 1-1-79

Serial Number 5A Mine D Trial # P

Tape (Y or N) Y

1. Connect the dots in the diagram below to show the steps the trainee took in donning the SCSR. If a step was started but not finished, simply dip the line toward the step. Do not touch the dot if the step was not completed or was done incorrectly.



2. After the task is completed please list any errors that need to be corrected and then correct them.

- Miner Stood up To Put unit on
- Mouthpiece/Noseclips Pulled out Several Times Since Trainee Failed To Adjust Neckstrap
- He Finally Decided To Kneel To Put Waist Strap on But Didn't Snug it
- He Forgot Goggles
- Subject was Extremely Nervous and unsure of exactly what to do. He Did Get His Lungs Isolated

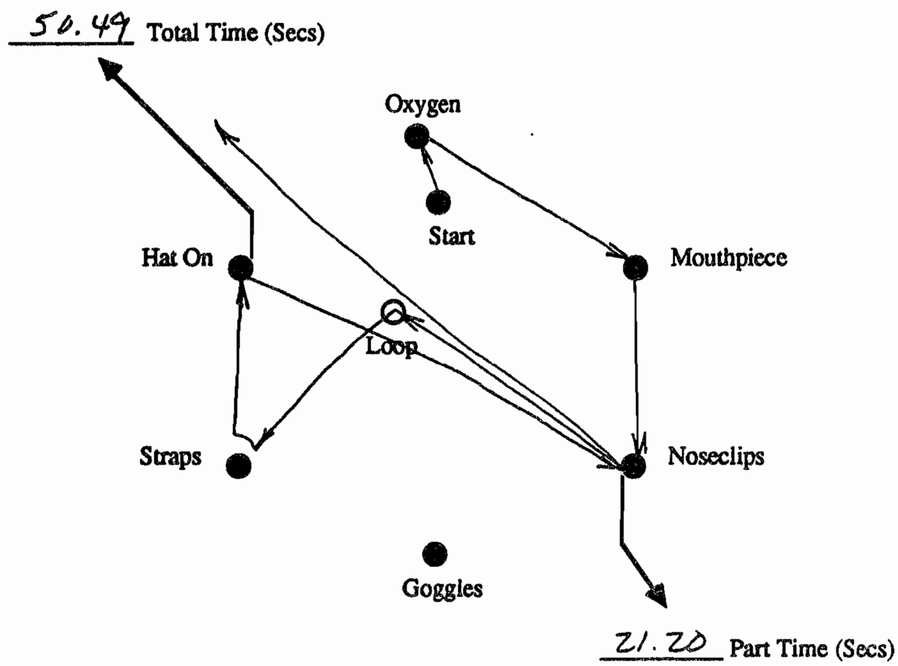
Figure 3.—Evaluation form for poor performance.

Evaluation for HD Date 1-1-89

Serial Number 09T Mine H Trial # M

Tape (Y or N) Y

1. Connect the dots in the diagram below to show the steps the trainee took in donning the SCSR. If a step was started but not finished, simply dip the line toward the step. Do not touch the dot if the step was not completed or was done incorrectly.



2. After the task is completed please list any errors that need to be corrected and then correct them.

- SUBJECT DIDN'T PUT ON GOGGLES
- HE DIDN'T CONNECT AND SNUG WAIST STRAP
- NOSECLIPS SLIPPED OFF AT END BUT HE PUT THEM BACK ON

Figure 4.—Evaluation form for marginal performance.

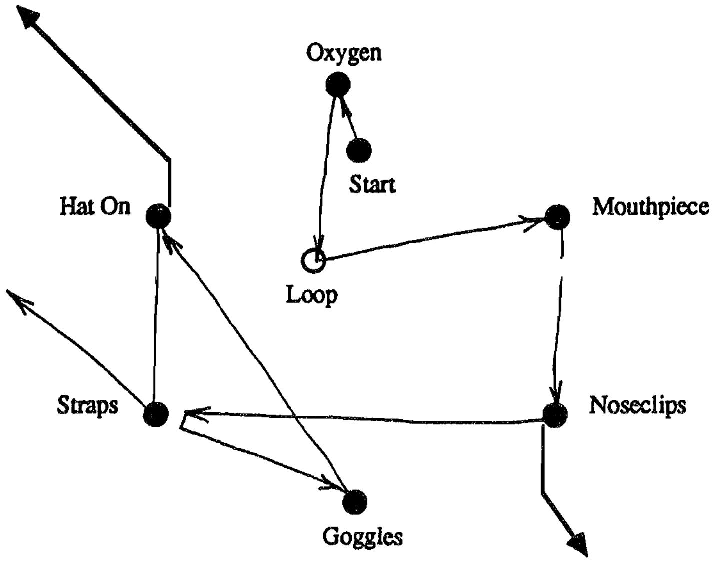
Evaluation for FD Date 1-1-89

Serial Number 075 Mine F Trial # A

Tape (Y or N) Y

1. Connect the dots in the diagram below to show the steps the trainee took in donning the SCSR. If a step was started but not finished, simply dip the line toward the step. Do not touch the dot if the step was not completed or was done incorrectly.

94.69 Total Time (Secs)



31.94 Part Time (Secs)

2. After the task is completed please list any errors that need to be corrected and then correct them.

- Subject Mixed Sequence
- He Adjusted Neckstrap Before Donning Goggles
- He Put on Hat, Then Snapped and Snugged Waist Strap

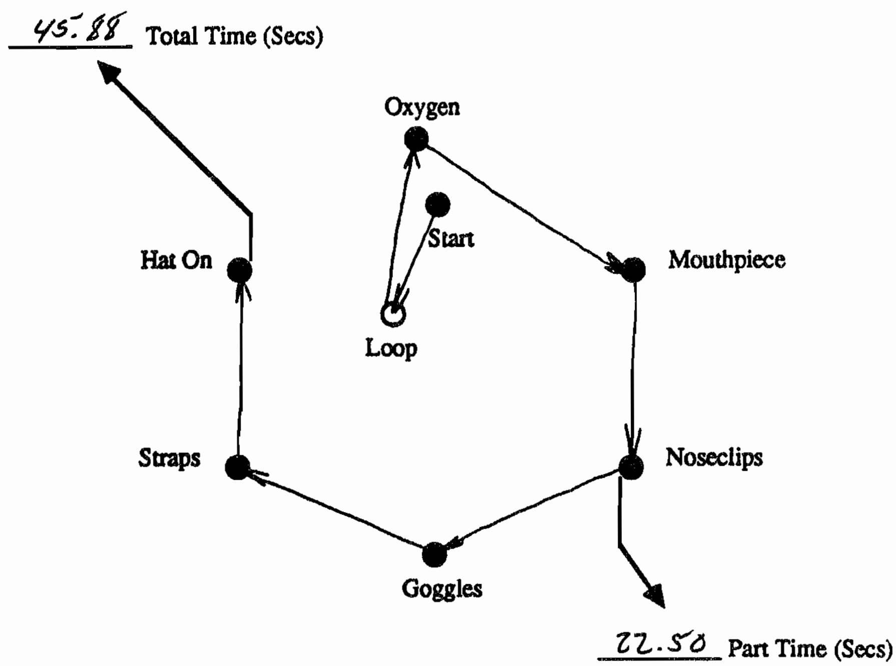
Figure 5.—Evaluation form for adequate performance.

Evaluation for MB Date 1-1-89

Serial Number Z9A Mine D Trial # PT

Tape (Y or N) N

1. Connect the dots in the diagram below to show the steps the trainee took in donning the SCSR. If a step was started but not finished, simply dip the line toward the step. Do not touch the dot if the step was not completed or was done incorrectly.



2. After the task is completed please list any errors that need to be corrected and then correct them.

PERFECT 3 > 3 SEQUENCE

Figure 6.—Evaluation form for perfect performance.

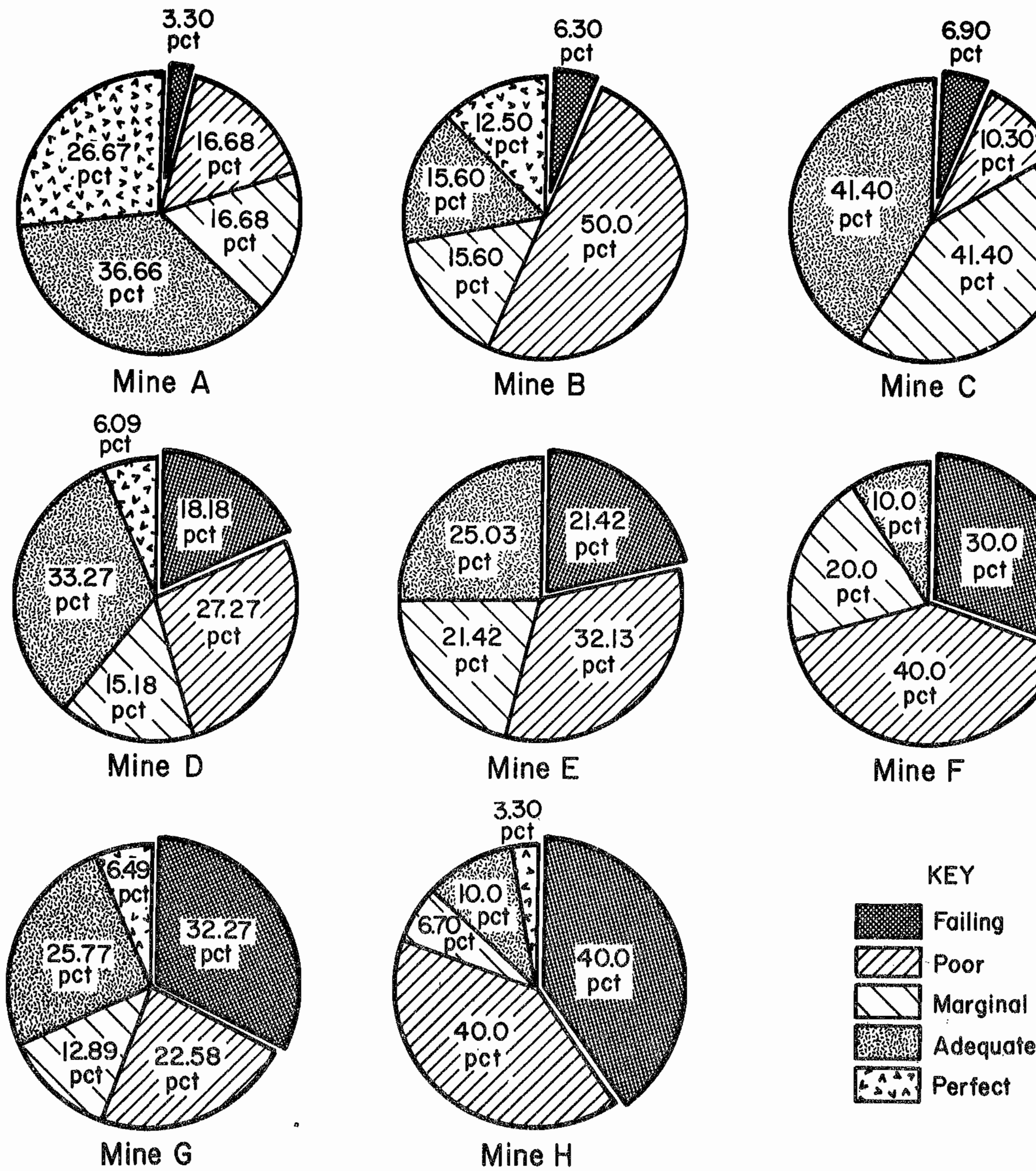


Figure 7.—Donning proficiency profiles for samples at eight mines.

prepractice instruction was given individually, with the trainer talking the miner through the 3+3 procedure one step at a time as the worker actually put the apparatus on. The complete procedure (including mouthpiece insertion) was taught using training apparatus equipped with quick-release snap clamps and replaceable mouthpiece assemblies. Second, the trainee was required to practice donning the SCSR, without prompting, and was evaluated with the 3+3 evaluation form. The 3+3 evaluation form was then used to give feedback after each trial performance. Third, the individual practiced until he or she had done five perfect sequences. Finally, the miners at this site were given the opportunity to practice donning the SCSR at least once more sometime during the year.

Within a week after their initial training, 30 miners at the site were selected randomly for a follow-up evaluation. This evaluation followed the same protocol that was used for evaluating the sample in the present study. An examination of the graphic depicting mine A (fig. 8) at 1 week after training and mine J at 1 week after training

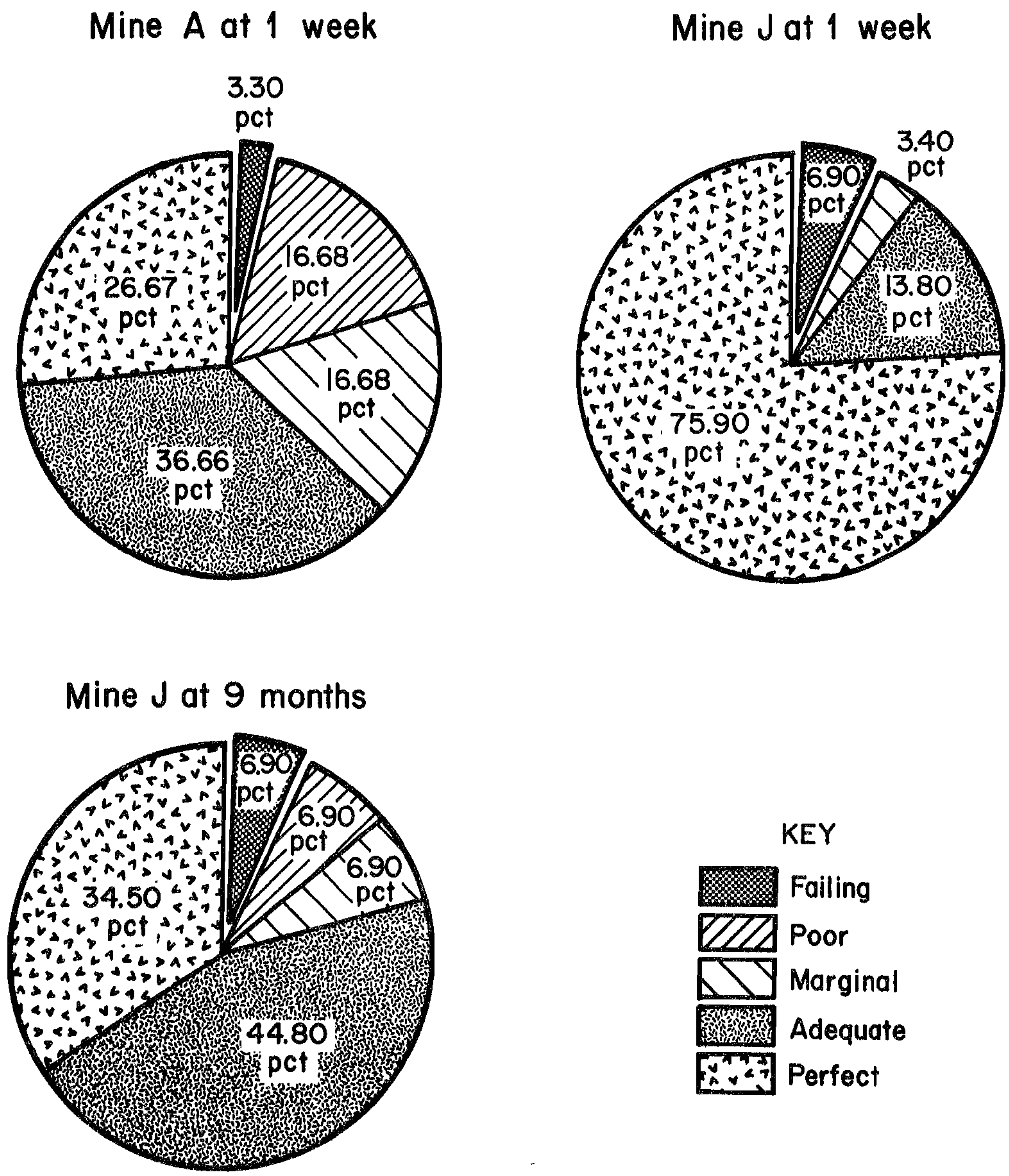


Figure 8.—Comparison of donning proficiency 1 week after training at mine A with proficiency at western mine 1 week after training.

shows that, even when trainers are teaching the same procedure (the 3+3), attention to the basic principles of motor task training will yield significant results. In fact, these desirable outcomes hold up over time. The same individuals at the western mine, when evaluated 6 to 9 months later, still exhibited high levels of proficiency. As the pie chart characterizing the 9-month evaluation shows, however, there was a significant amount of forgetting over time. Over half of those who did a perfect sequence originally fell into one of the other categories. The proportion of marginal performance doubled, and there were, at 9 months, some miners who fell into the poor category. If the pattern seen at the western site is extrapolated to mine A, it is easy to see that the mine A workers, who were not trained so well initially, would look much less proficient at 9 months. The key to achieving and maintaining SCSR donning proficiency, therefore, can be summed up in one sentence: Train well initially, and be prepared to offer thorough, consistent, hands-on practice periodically.

ERROR PROFILE OF SAMPLE

Table 1 shows the frequency of errors made on each step in the donning procedure. Errors were not counted twice. Thus, if an individual made a sequencing error while inserting the mouthpiece, took it out, put it back in, but failed to get a good seal, the miner would only be credited with one mouthpiece error. By the same token, if a miner made a mouthpiece error and subsequently corrected it, the miner would still be charged with having made an error. Also, an individual can be represented more than once in this table, since it is possible to make an error on more than one step.

Concerns voiced early in the study involved questions regarding the willingness of miners to insert the mouthpiece during the donning trial. The reason given for the expected refusal was that trainers did not typically require insertion of the mouthpiece during refresher training.[7] As was mentioned earlier, insertion of the mouthpiece during the present study was not an issue: once miners were assured that the mouthpiece assembly had been sanitized, they were quite willing to cooperate. However, most of the miners in the sample had periodically demonstrated a broken sequence. The break occurred when the miner would perform the steps up to insertion of the mouthpiece, then stop, explain how to insert, and continue with the remaining steps. An interesting finding, therefore, was the frequency of mouthpiece errors committed by individuals when they attempted to insert the mouthpiece. Mine E and mine H had the highest frequency, followed by mine D. Even mine A, where the miners had just been trained, had five people who made mouthpiece errors. Included is the sample from the western mine, where everyone inserted the mouthpiece as part of their training, as point of comparison. One person in this group, taught to do the complete 3+3 sequence, committed a mouthpiece error upon being evaluated some 9 months after training.

Another interesting aspect of the error profile is the percentage of miners in the sample who put the noseclips on before inserting the mouthpiece. This was done although it is an awkward reversal of steps, and no training materials recommend that sequence. Table 2 shows that, of those who did both steps, a noticeable percentage of miners at mine B, mine H, mine C, and mine G made this sequencing error. At mine D, almost half (43.8 pct) of the miners put the noseclips on before attempting to insert the mouthpiece. The most likely explanation for this phenomenon is that in hands-on training where mouthpiece insertion is simulated, the real sequence of steps is to activate the oxygen and then to put on the noseclips. Therefore, even when mouthpiece insertion is to be performed, as it was in this series of evaluations, the sequence stays confused for a sizeable proportion of people. They are in effect omitting the mouthpiece step initially.

[7] Mouthpiece insertion is skipped because of concerns about the spread of contagious diseases, the effort and expense required to sanitize mouthpieces, and the fact that simulation of mouthpiece insertion is acceptable under the mandated training regulations.

Table 1.—Donning errors by mine

Procedural step	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H	Mine J[1]	Total
Loop neckstrap over head	2	7	2	1	7	8	3	9	1	10
Activate oxygen	0	0	1	4	1	2	6	1	3	18
Insert mouthpiece	5	7	7	8	11	7	5	16	1	73
Put on noseclips	6	7	6	6	9	6	7	10	2	59
Put on goggles	0	10	6	3	4	15	7	3	10	58
Adjust straps	18	26	8	15	12	24	17	26	9	155
Replace hat	0	6	11	3	6	19	5	7	1	58

[1] Western mine.

Table 2.—Percentage of miners who put noseclips on before mouthpiece

Noseclips put on—	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H	Mine J	Total or average
Before mouthpiece:										
Number	0	5	6	14	2	2	5	4	1	39
Pct	0	16.1	21.4	43.8	8.0	7.1	16.7	15.4	3.6	15.2
After mouthpiece:										
Number	29	26	22	18	23	26	25	22	27	218
Pct	100	83.9	78.6	56.3	92	92.9	83.3	84.6	96.4	84.8
Total number	29	31	28	32	25	28	30	26	28	257

The problem with changing a sequence, once taught, is illustrated by an analysis of 624 SCSR donning trials conducted by the Bureau in 1986 and 1987. During these trials, there were 275 omitted steps. Only 90 of the omissions were subsequently corrected by the individual in the process of putting on the SCSR. A logical conclusion is that when individuals skip a step, they usually continue with the donning procedure and do not go back and correct themselves. It has also been observed that when a person skips a step and does attempt to correct the omission, he or she may become confused and prone to error.

Table 3 looks at the problem from a slightly different perspective. This table draws upon data taken both from 177 individuals originally trained to insert the mouthpiece during Bureau research, and the 243 miners in the present study. It indicates the outcome for people who first put on the noseclips, and then either attempted to insert the mouthpiece or omitted it entirely. As can be seen, 28 of the 67 people (41.8 pct) who initially omitted the mouthpiece step subsequently failed.

Table 3.—Percentage of miners who put noseclips on before mouthpiece and subsequently failed

Miners	Trained to insert mouthpiece	Not trained to insert mouthpiece	Total or average
Failed:			
Number	14	14	28
Pct	56.0	33.3	41.8
Isolated lungs:			
Number	11	28	39
Pct	44.0	66.7	58.2
Total number	25	42	67

Table 4 is related to the other three, but illustrates the problem of mouthpiece insertion from yet another slightly different perspective. This table draws upon the same two data bases mentioned above, and simply shows what proportion of failures is due to mouthpiece error no matter what the sequence. As can be seen, a significantly larger percentage of all failures among the sample in which mouthpiece insertion is not routinely taught can be attributed to mouthpiece error (58 vs. 25 pct).

Table 4.—Failures due to mouthpiece errors

Miners	Trained to insert mouthpiece	Not trained to insert mouthpiece	Total or average
Mouthpiece errors:			
Number	9	29	38
Pct	25.0	58.0	44.2
Other critical errors:			
Number	27	21	48
Pct	75.0	42.0	55.8
Total number	36	50	86

In summary, table 1 merely profiles error frequency by mine. Table 2 indicates a tendency among a sizable proportion of the present sample to change the donning sequence by putting on the noseclips and then inserting (or attempting to insert) the mouthpiece. Table 3 illustrates the consequences of omitting the mouthpiece step until after the noseclips have been put on by showing that over 40 pct of the people who did this subsequently failed to get their lungs isolated (although the reason for the failure varies). Finally, table 4 suggests that trouble with the mouthpiece is not as much a reason for failure among those who have originally been trained to insert the mouthpiece as among those who have not.

SAMPLING AND QUALITY CONTROL

The random selection of miners within each of the eight sites and the size of the samples (approximately 30 miners at each site) allow the use of probability theory to draw inferences about the donning proficiency of the workforce at each of the eight mines sampled. The inferences one could make from the data would concern the proficiency level of all miners at the site, based upon some observed proportion in the sample (percent failing or percent perfect for instance).

Suppose a trainer is willing to tolerate a proficiency profile at his or her mine in which 10 pct of the workers fail to isolate their lungs during a SCSR donning evaluation. If the mine is small, it might be possible to evaluate everyone who goes underground. This trainer could then characterize the total workforce using descriptive statistics offering an absolute profile of worker's competency in SCSR donning. If, however, the population of the mine is large, it might not be feasible to evaluate everyone. Therefore, the trainer would have to evaluate a random sample, and make inferences about how well the statistics he or she uses to characterize the sample reflect on the population.

Finding a 10 pct failing rate in the sample would not necessarily mean that the proportion of failures in the population is 10 pct. In fact, such coincidence would be highly unlikely. The true proportion of all miners in the failing category might be 8, 12, or 20 pct. The reason for this is that samples, no matter how careful one is to use good randomization techniques when they are drawn, seldom reflect all the variation that might be found in the population. For this reason, sample size is obviously important, along with a random selection of miners (giving all elements of a population an equal chance of being selected). Both these factors help to increase confidence in the types of inferences one can make about the population based on performance within the sample.

In essence, what one does when making inferences about a population based on sample characteristics is test the hypothesis that there is no significant difference between the sample proportion (in this instance, percentage of all people in the failing category), and the proportion that would be found in the population if the entire population were evaluated. An accepted convention is to use the 95 pct probability figure in deciding whether to accept or reject this hypothesis. Outcomes are always either 1 or 0: a person either wins the lottery or does not. What the 95 pct probability figure means, however, is that if a person took an infinite number of random samples from a population and determined a proportion for each sample (percent failures, for instance), 95 pct of those observed proportions would be within plus or minus 1.96 standard errors of the true population proportion. Five percent of the observed proportions would be outside these limits. Since 95 pct of all observed proportions will be within plus or minus 1.96 standard errors of the true population proportion, one can use this information to construct a confidence band around any particular observed proportion in a sample.

The first step is to find the standard error of the observed proportion. This is done by taking the square root of the observed proportion (p) multiplied by 1 minus the observed proportion (since outcomes are always 1 or 0) and divided by the number (n) in the sample:

$$\text{Standard Error} = (p)(1-p)/n.$$

The confidence limits can then be expressed as:

$$\text{Confidence Limits} = p \pm 1.96 \; ((p)(1-p)/n).$$

Since 95 pct of the sample proportions observed will be within plus or minus 1.96 standard errors of the population proportion, and one uses plus or minus 1.96 times the standard error of an observed proportion to construct a confidence interval around it, then 95 times out of 100 this confidence interval will capture the true proportion. Thus, there is a one in 20 chance that the true population mean is outside of the confidence band.

It was suggested earlier that one way to increase the confidence in a sample is to increase the sample size. Increasing the sample size decreases the standard error, and hence narrows the confidence interval. Figure 9 illustrates a practical application of this logic. It shows confidence intervals for proportions that might be observed with samples of size 30 (*6*). P, given on the vertical scale, is the true population proportion for a particular observed sample proportion (p = r/n on the horizontal scale). Suppose an evaluation of 30 miners resulted in nine failures. The 95 pct confidence limits for an observed proportion of 30 pct (shown as 0.3 on the horizontal scale), when the sample size is 30 (indicated by the outermost curved lines), are approximately 15 and 50 pct. Intuitively, 95 pct of all observed proportions of 30 pct, taken from samples of 30, and having lower limits of 15 pct and upper limits of 50 pct, will contain the true population proportion. If the person doing the evaluation is satisfied with a true failure rate of at least 15 pct, then the fact that he or she had a sample proportion of 30 pct in the failing category would not be unusual.

Establishing confidence limits around observed sample outcomes has certain advantages for those taking a quality control approach to hypothesis testing. First, it divides all possible outcomes into two sets: those that are likely, and those that are not. Therefore, at the same time one rejects the null hypothesis of no significant difference between the observed sample proportion and the true population proportion, one can also make statements about what the parameters of some expected outcomes are likely

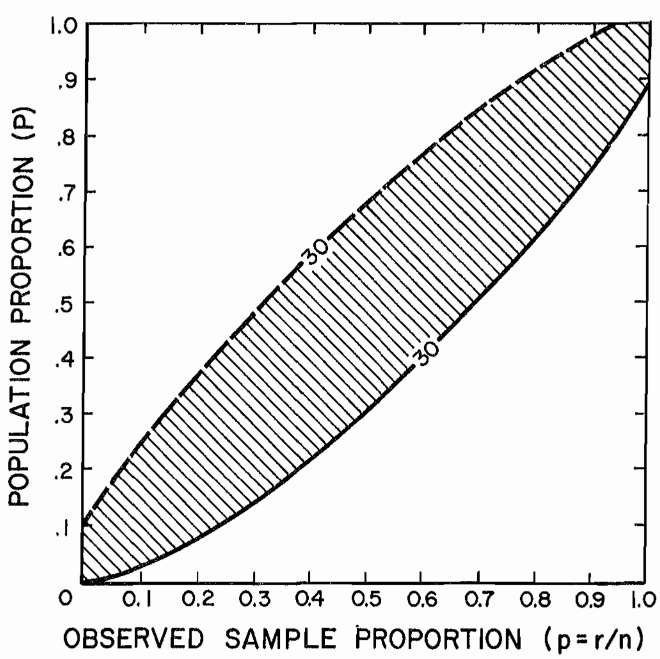


Figure 9.—Confidence intervals.

to be. Second, the greater the distance of the observed outcome from the confidence interval, the more clear-cut the choice of whether to accept or reject a hypothesis of no significant difference (*7*).

In taking a quality control approach to SCSR donning proficiency, the evaluator would only be concerned with whether the characteristic proportion observed in the sample exceeds some predetermined standard. In this case, he or she would use the lower confidence limit, because there is no interest in an observed proportion that might be significantly less than the standard. If, then, the trainer or training specialist decides that he or she will tolerate no more than a 10-pct failure rate at a mine, the two points of interest on the first graphic in this section would be the lower confidence interval (represented by the curved lines) and the dark horizontal line drawn at 0.1 on the vertical scale (representing a true population proportion of 10 pct, the standard). For a sample of 30, the two lines intersect at an observed sample proportion of approximately 23 pct. Anything to the left of this intersection is "within tolerance," and anything to the right can be rejected with a high degree of certainty that the true population proportion of failures is more than 10 pct.

Figure 10 uses the procedure discussed above to show which mines in the Bureau's sample have proportions of failures outside the confidence band, and therefore would almost certainly have a failure rate of more than 10 pct if all workers at the operation were evaluated. Assuming that samples were drawn randomly, there is still a drawback to the use of this procedure that deserves a caveat. While it is necessary to have a sample size of at least 30 in order for the sampling distribution to be normal in shape, there is a rule of thumb that the sample should not exceed 5 pct of the population. The reason for this is that sampling without replacement limits the number of cases available to be selected as more and more are removed from the population (*8*).

Mine A was so small that its sample of 30 constituted 56 pct of the population. With this exception, mines in the present study had between 9 and 14 pct of their populations in the samples taken. Since the binomial distribution is of questionable validity when sampling without replacement from finite populations, the hypergeometric distribution was used to calculate 95 pct confidence limits for the mines. There was only a slight difference in outcomes: Mine E changed its place from within the confidence limit to outside it.

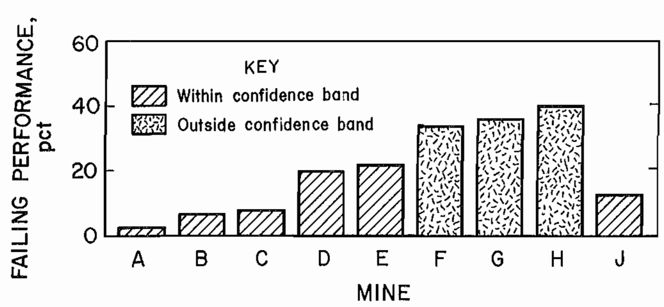


Figure 10.—Percentage of miners failing to isolate their lungs (by mine.)

Treating mine A as a special case requiring descriptive statistics, it was decided to focus on whether the quality control graph depicted in figure 9 could have a practical, though admittedly crude, application to the problem of trying to draw inferences about workforce proficiency from sample performance. While use of the binomial distribution led to wider interval ranges, the hypergeometric test suggested that using the binomial would not lead to significant error in forecasting SCSR proficiency at the other mines. The point to be remembered here is that, while random sampling can allow us to make inferences about the population within certain limits, there is not a one-to-one correlation between what one observes in a sample and what one is likely to find in the population.

DISCUSSION

This report has suggested that sampling and evaluation might be used to promote competency based training. The confidence bands (fig. 9) can be used here, too. Suppose that instead of focusing upon failures, a trainer decides that his or her workforce should be competent with the SCSR. The usual criterion for defining competence is that a person must be able to do a task correctly. Again, following convention, he or she determines that to consider the miners competent, 90 pct of the population ought to be able to don the apparatus proficiently (fall into either the perfect or adequate category). Assuming a sample of 30, the trainer would locate the 90 pct true population proportion on the vertical scale (given here as 0.9) and locate the confidence intervals that would include this proportion 95 pct of the time. The lower limit, reading across, is approximately 77 pct. Therefore, he or she would need a combined observed proportion of perfect and adequate performers totaling at least 77 pct to consider the workers competent. As figure 7 indicates, none of the eight mines met this criterion. There appears to be much room for improvement if one focuses on donning proficiency. The error profiles for each of the mines (table 1) offer some specific guidance and targets for improvement.

Finally, as figures 7 and 8 imply when comparing the eight-mine sample to the western site, it is not prohibitively difficult to achieve and maintain competence in donning the SCSR. The primary requirements are attention to detail when training, feedback or knowledge of results, periodic follow-up evaluations, and the opportunity to practice when needed.

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